Conclusions and Recommendations

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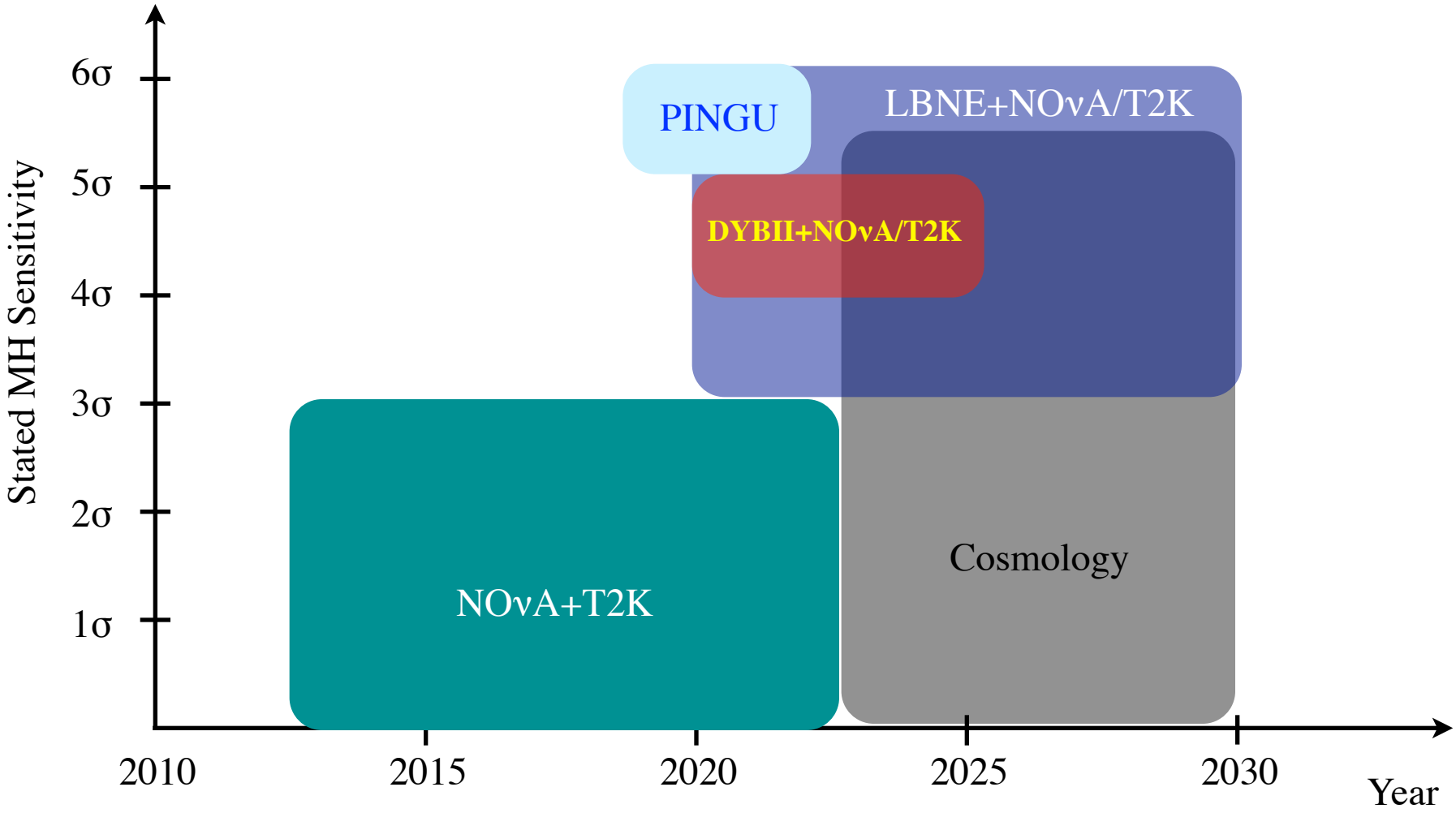
Charge

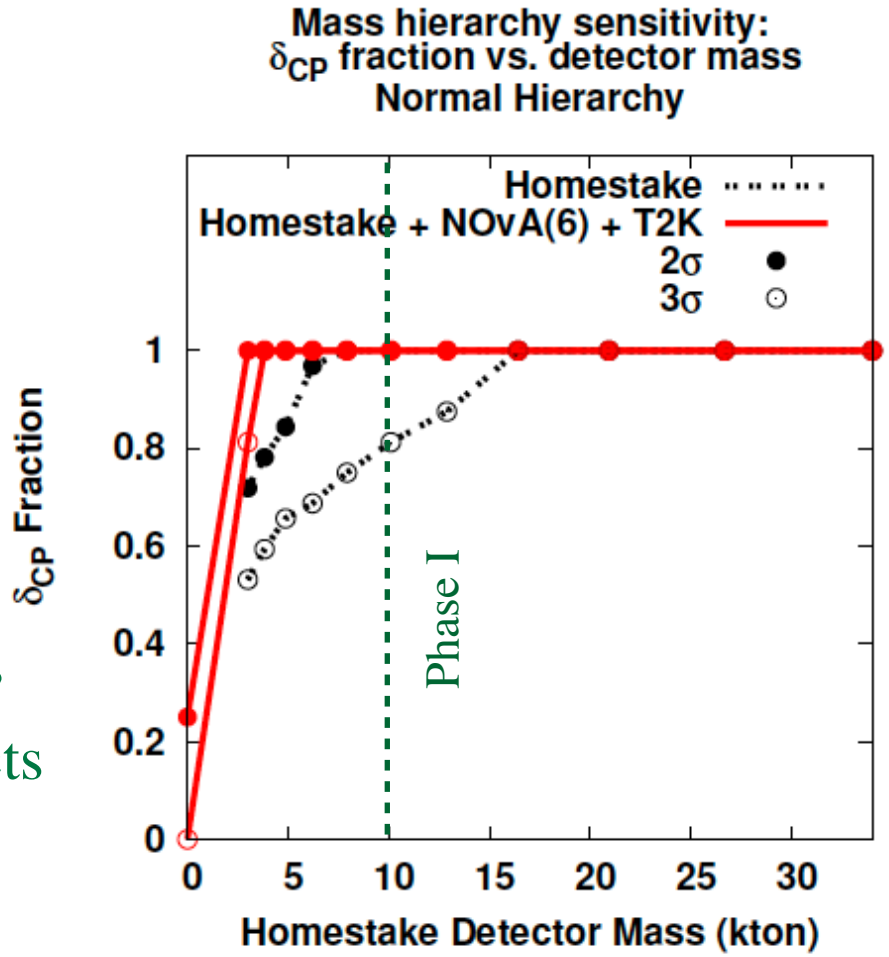
- Survey the experimental techniques that can be used to determine the neutrino mass hierarchy, or alternately, measure a quantity sensitive to the sum of neutrino masses with sufficient accuracy to distinguish the inverted from the normal hierarchy if the sum is found to be sufficiently small.
  Include accelerator, reactor, underground ($0\nu\beta\beta$) and cosmological approaches.
  Comment on the strengths and weaknesses of the different methods.
- Summarize the proposed experiments within each category and estimate the likely time scale for a neutrino mass hierarchy measurement at 1, 2, 3, 5 sigma. What are the limiting factors (statistical and systematic) for each?
- Recommend any new programmatic directions that are particularly compelling and competitive that should be considered for future investment by PD and/or NSD.

Timescale and Sensitivity



LBNE

- >3σ stat significance for determination of MH in (in combination with NOvA +T2K) independently of δ_{CP}
  - Major part of US program
- However:
  - Timescale & cost, could be scooped by other measurements
  - Poorly understood nuclear effects
  - Limited scope (MH, δ_{CP})
  - Small involvement at LBNL at present

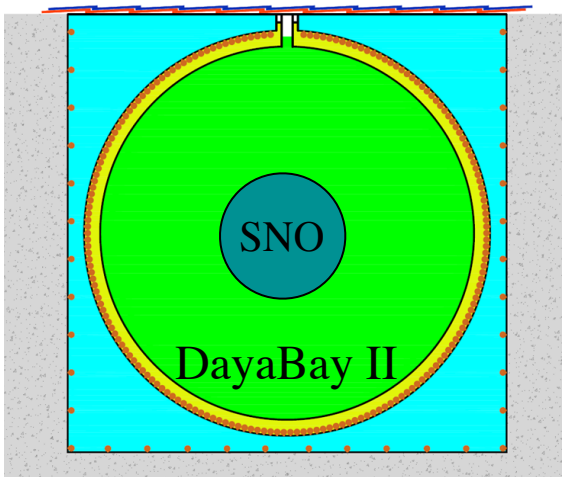


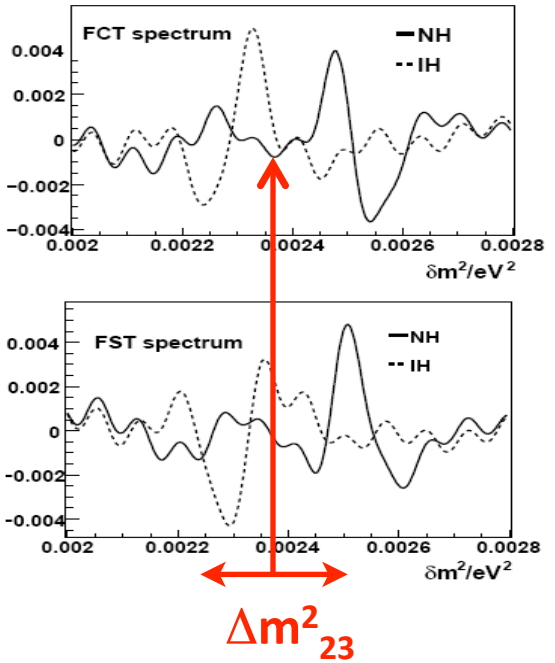
LBNE Recommendations

- Consider major participation *if* opportunities for *leadership* role and resources required to take them on are identified
  - Opportunities exist that match division expertise
  - Leadership role requires increase in involvement, or partnership with other UCs and labs
- Without significant leadership role, a limited involvement is possible that builds on existing strengths

Reactor Neutrinos (DayaBay II)

- Statistical sensitivity to MH
- Major Chinese project (will happen)
- Very challenging measurement
  - Requires major improvements in detector technology (multiple factors of 2)
  - Energy resolution and scale are of paramount importance
  - Requires percent-level precision on Δm^2_{23}
- Collaboration politics may impede major role for LBNL



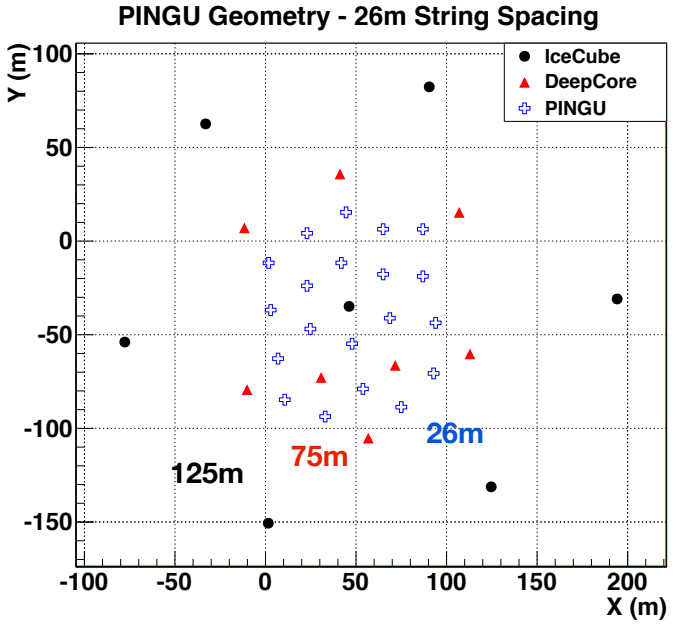


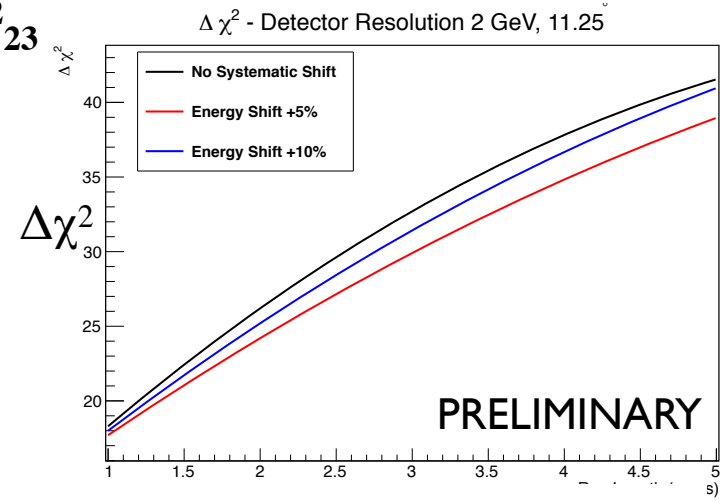
DayaBay II Recommendations

- Physics and Nuclear Science Divisions have considerable expertise in similar experiments
- Seriously consider involvement if techniques are identified to mitigate the systematic issues
  - Probably requires a dedicated task force to address detector calibration
  - Also consider the likelihood of LBNL playing a leadership role in physics
    - ☞ E.g. calibration system has been offered for international involvement

Atmospheric Neutrinos (PINGU)

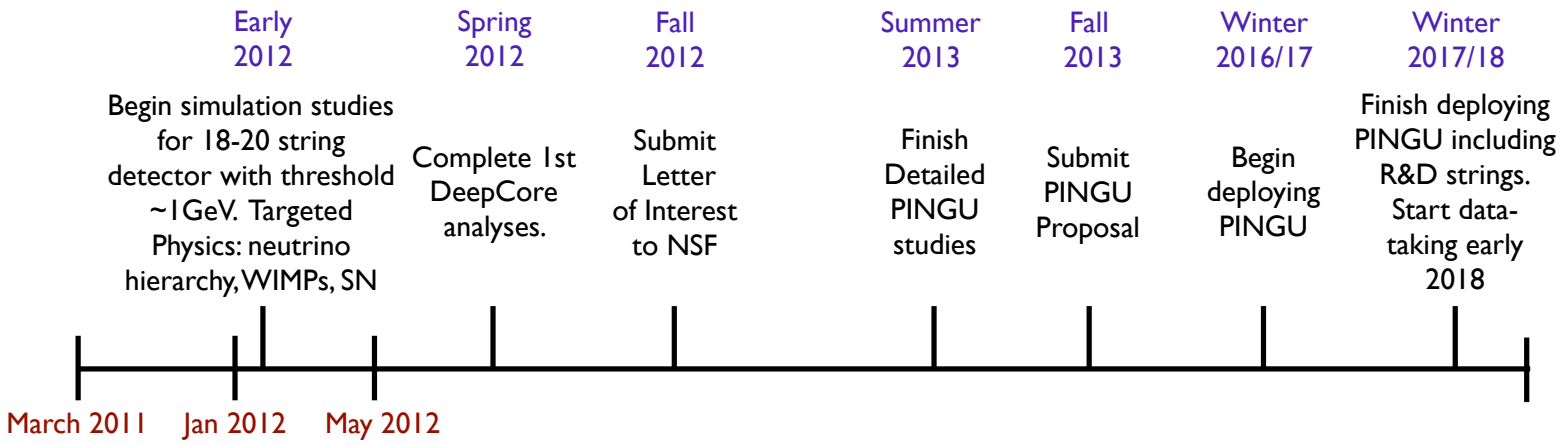
- Excellent statistical sensitivity to MH
- Issues
  - Energy resolution and scale
    - ☞ Impact on sensitivity
    - ☞ Practical calibration techniques
  - Additional uncertainty due to Δm^2_{23}
  - Small collaboration: unclear how these will be addressed
  - NSF vs DOE





PINGU Recommendations

- NSD and PD have experience and expertise in IceCube
- Consider involvement if it is determined how the systematic issues can be reliably mitigated
  - Probably requires a dedicated task force to check calculations and address detector calibration



Cosmological Constraints

- Cosmological fits are sensitive to the *sum* of neutrino masses
  - Direct determination of MH is possible iff MH is normal (sum of masses is small)
    - ☞ Complementarity to terrestrial measurements
- LBNL+campus already have a vibrant and multi-pronged program in cosmology
  - ☞ Opportunity to seize leadership in global analysis and analysis infrastructure
  - ☞ Focus on neutrino mass measurements, their systematics and model uncertainties would be particularly appropriate for LBNL

Final Thoughts

- Historically, new projects at LBNL have been initiated by people interested in the science
- We hope these presentations will stimulate interest
  - And people will vote with their feet